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ADP012732

TITLE: Electron Velocity Modulation Under Lateral Transport in the Weakly-Coupled Double Quantum Well Structure

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Electron velocity modulation under lateral transport in the weakly-coupled double quantum well structure

P. I. Birjulin, S. P. Grishechkina, I. P. Kazakov, Yu. V. Kopaev, S. S. Shmelev,
V. T. Trofimov, M. V. Valeyko and N. A. Volchkov

P. N. Lebedev Physical Institute of RAS, Leninsky pr., 53, Moscow 117924, Russia

Abstract. Large electron velocity modulation was found under lateral transport in the GaAs/AlGaAs weakly coupled quantum well structure. It manifests in extremely strong dependence of the lateral conductance on the transverse electric field (gate voltage) as well as in the step-like shape of the lateral current on the lateral (source-drain) voltage.

Introduction

The lateral transport properties of the coupled quantum wells are subject of wide investigation in connection with the search for the conductance modulation mechanisms that would not change the carrier concentration in the conducting channel. If the average number of carriers in the conducting channel of the structure remains constant the high-frequency limit of conductance modulation increases as the channel capacitance needn't be recharged.

Structures and measurements

The structure consisted of two GaAs quantum wells separated by $\text{Al}_{0.3}\text{Ga}_{0.7}\text{As}$ barrier of 500 Å width. The lower non-doped quantum well QW1 of 200 Å width was combined by AlGaAs barrier layers, while upper triangle one QW2 was formed in Si-doped GaAs cap layer near barrier interface. The electron mobilities at 300 K were about 8500 and 1500 cm^2/Vs for the QW1 and QW2 respectively. Sheet carrier concentration in the conductive channel was about 10^{12} cm^{-2} . Samples for measurements were prepared in the field effect transistor configuration with a Shottkey barrier gate, its length and width being 15 and 50 μm respectively. Ohmic contacts were formed by alloying of Au-Ge-Ni eutectics so that to provide reliable contact to both quantum wells. Normally open channel was driven by negative gate voltage. The lateral current dependences upon transverse electric field (gate voltage) and lateral potential difference (source-drain voltage) were measured at 77 and 300 K.

Experimental results

Transistor channel conductivity dependence on the gate voltage was found to be non-monotonic for source-drain voltage higher than 0.6 V at room temperature (Fig. 1). Drain potentials are equal 0.1, 0.7, 1.25, 1.75, 2.25, 3.5, 4.5 V for curves 1–7, respectively. The transconductance increases up to extremely high value of 6 A/V at 4.5 V, and small auto-oscillations of lateral current are observed. The effect of the gate potential on the structure conductance significantly decreases as the temperature drops to 77 K. Figure 2 shows the dependences of the lateral current on the source-drain voltage,

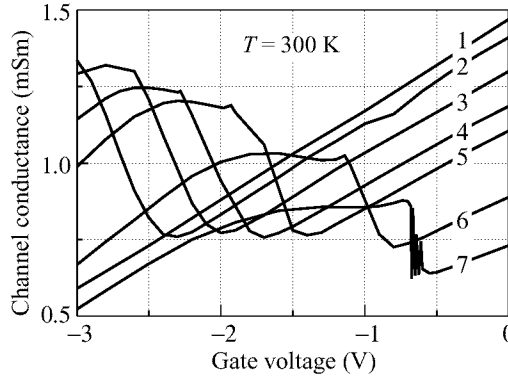


Fig 1. The channel conductance dependence on the gate voltage. The curves are plotted for the following source-drain voltages: (curve 1) 0.1 V; (curve 2) 0.7 V; (curve 3) 1.25 V; (curve 4) 1.75 V; (curve 5) 2.25 V; (curve 6) 3.5 V; (curve 7) 4.5 V.

the gate potential being 0, -0.8 , -1 , -1.2 , -1.5 V for the curves 1–5, respectively. Sharp increase of the lateral current occurs at the drain potential, corresponding to the transconductance sign inversion. Saturation of the current is observed at higher drain potential. At the highest source-drain voltage the current drops again for some samples (curves 2 and 3).

Model

We explain the results by the electron tunneling between connected in parallel quantum wells with different saturation velocity of carriers in high electric field. Electron velocity saturates as a result of carrier heating, because lateral electric field magnitude exceeds 3 kV/cm. Field distribution along the structure differs for two quantum wells due to their different distance from the gate. Therefore, large potential difference between the wells occurs in the vicinity of positive electrode (drain), being comparable with lateral potential drop of the structure. The barrier between the wells becomes transparent for tunneling at high (up to 10^5 V/cm) electric field, that leads to redistribution of the wells currents and to the modulation of the structure conductance. Figure 3 shows the result of calculations of the first quantum level and Fermi level positions along the structure in QW1 and QW2. They was obtained from simultaneous solution of 2D Poisson and drift-diffusion equations. The drain and gate potentials were taken to be 3 and -1 V respectively.

The main mechanism of the current leakage between the wells is supposed to be thermal excitation of the carriers to the higher quantum levels and their further tunneling, because drive effect significantly decreases as temperature drops to 77 K. Also, the transition from QW2 to QW1 through the AlGaAs barrier is caused by the carriers overheating by the lateral electric field. The potential difference between two wells can be increased by drain voltage increase or by gate voltage decrease. Electron transitions to the lower quantum well with higher saturation velocity lead to the increase of the channel conductance. It causes non-monotonic drain current dependency on the gate voltage (Fig. 1) and current jumps in I–V characteristics (Fig. 2) as well. The effect

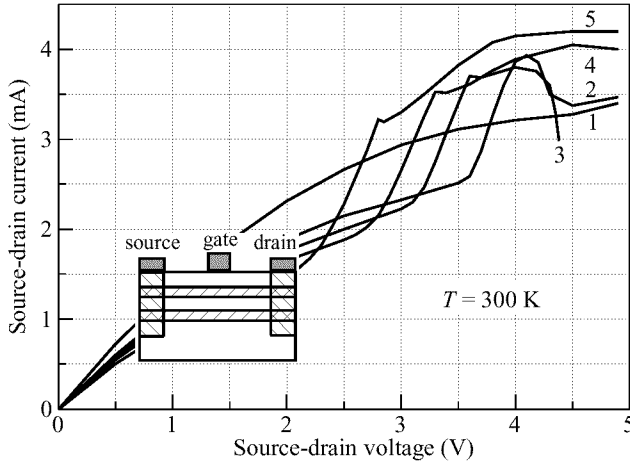


Fig 2. I-V characteristic of the channel. The curves are plotted for the following gate voltages: (curve 1) 0 V; (curve 2) -0.8 V; (curve 3) -1.0 V; (curve 4) -1.2 V; (curve 5) -1.5 V.

is amplified by the positive feedback between tunneling electric current and transverse potential difference.

Thus, conductance modulation of proposed GaAs/AlGaAs structure with two quantum wells is the result of coupling in high electric field, which is produced by drain voltage and controlled by a small change of gate voltage. The investigated phenomenon can be used for the development of p-type field effect transistor simulators (channel is opened by negative gate bias) with high transconductance, carriers being electrons instead of holes.

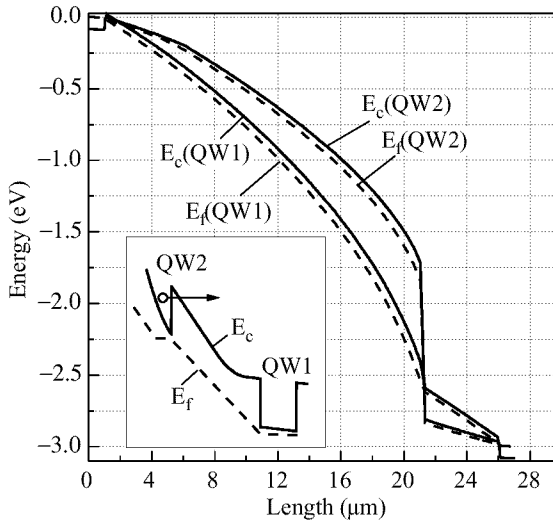


Fig 3. Calculated positions of the first quantum level and Fermi level along the structure in QW1 and QW2. The drain and gate potentials are 3 and -1 V respectively.

The work was financially supported by the Russian Foundation of Basic Research.

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